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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking Politecnico de Torino as follows: B. TECHNICAL PROPOSAL/DESCRIPTION OF WORK:
Aim of the project is to fabricate and characterize rare earth doped soft glass optical fibers for fiber lasers emitting at wavelengths longer than 2 micron to allow efficient narrow linewidth emission in the atmospheric window useful for coherent detection and sensing. The research activity will focus on the design of the laser host material in terms of suitable glass composition and rare earth doping (quality and quantity of the dopants), then fiber preform fabrication and fiber drawing will follow with the aim of maximizing dopant concentration (which induces a reduction of the laser cavity), lifetime of the upper laser level and emission cross section. Proof of concept of fibers suitable for single-frequency operation will be demonstrated. Understanding of the active material suitable for optimum laser design is expected as final result.
The investigated host material for the incorporation of rare earth ions will be tellurite glass because it is a better candidate than silica for emission above 2 micron: it shows high transparency (up to 6 micron), lower phonon energy (700 cm-1 vs. 1100 cm-1), higher rare earth solubility (up to 10 mol% of Ln_2O_3). These properties should allow the fabrication of short cavity narrow linewidth (also called single frequency) optical fiber lasers and in general of compact active devices. The main rare earth dopant will be Ho^{3+} ion, which features emission at wavelengths longer than 2 micron. Since Ho does not allow efficient direct pumping with laser diodes, Tm and Tm/Yb co-doping will be carried out and pumping at 790 and 980 nm will be investigated, respectively.

15. SUBJECT TERMS

EOARD, Non-linear Optical Materials , optical materials

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POLITECNICO DI TORINO

Research project # FA8655-09-1-3111

Ho-doped soft glass optical fibers for coherent wavelength sources above 2 micron

4th Interim report – Final Report

(Jul 2010 – Sept 2010)

Author: Daniel Milanese

1 Introduction

Rare earth doped fiber lasers for emission in the infrared wavelength region above 1.55 micron are of great interest for several applications, including eye-safe LIDAR and DIAL systems for defence applications. In particular single frequency sources emitting above 2 micron would allow longer coherent length and thus better sensitivity for coherent detection at long distance, thanks to the atmospheric transmission window available.

The aim of the project is to develop and characterize rare earth doped soft glass optical fibers for fiber lasers emitting at wavelengths longer than 2 micron to allow efficient narrow linewidth emission in the atmospheric window useful for coherent detection and LIDAR and DIAL sensing.

2 Experimental

During this period the following activities were carried out:

a. Fabrication of a Tm-Ho doped tellurite glass preform
b. Drawing of a single mode tellurite optical fiber
c. Morphological and optical characterization of the Tm-Ho doped optical fibre
d. Fluorescence spectroscopy in the visible and in the near infrared wavelength ranges of the optical fiber by pumping at 793 nm.

3 Results

3.1 Fabrication of a Tm-Ho doped tellurite glass optical fibre preform

The following glasses were prepared in order to fabricate a single-mode Tm-Ho doped optical fibre. Their composition is in mol% and the rare earth oxides were added in wt%.

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Core glass: $75TeO_2$: 18ZnO: $7Na_2O$ + 1wt% Tm_2O_3 + 0.4 wt% Ho_2O_3
1^{st} cladding glass: $73TeO_2$:18ZnO: $9Na_2O$
2^{nd} cladding glass: $72TeO_2$: 18ZnO: 10 Na_2O

The minimum purity of the chemical precursors involved in this work was 99+%. The onset melting temperature was 750 ˚C and the duration of the process 2 hours. The melt was cast in a brass mould preheated to 300 ˚C and annealed at Tg – 10 ˚C for 2 h. Glass melting was carried out in a Pt crucible inside a chamber furnace. Core glass was melted twice: the first melting was carried out inside a glove box in controlled atmosphere in order to minimize the OH content inside the glass. OH contamination is extremely detrimental, in particular when emission in the near infrared wavelength region is targeted. For this process the core and 1^{st} cladding glasses went through a second melting step which had to be carried out in laboratory atmosphere to ease the casting procedure. The jacketing cladding tube was produced from the 2^{nd} cladding glass by the rotational casting technique at a rotational speed of 3000 rpm. The core/clad structured rod produced by built-in-casting was stretched down to a diameter of 3 mm to fit into the jacketing tube.

3.2 Drawing of a single mode tellurite optical fibre

The preform was drawn into fiber using a drawing tower developed in-house. The furnace consists in a graphite ring heated by an induction operating at 248 kHz and delivering 170 W to reach drawing temperature (SAET, Torino, Italy). The preform was fed into the furnace and drawn into fiber at speed of 2.5 m/min under a tension of 70 mN. About 150 m of fiber were manufactured.

In-line monitoring of fiber diameter allowed to determine a maximum diameter change of 3 µm in steady state conditions. This measurement also allowed selecting the suitable fiber parts for the following experiments.

3.3 Morphological and optical characterization of the Tm-Ho doped optical fiber

The fabricated optical fiber was first characterized by means of transmission optical microscopy in order to assess the morphology of the core and cladding shapes and features. In particular the core-cladding interface quality is of great importance because it allows minimization of scattering centers which would reult in higher attenuation loss of the overall fiber. Fig. 1 shows the optical micrograph of the fabricated optical fiber, taken with a reflex camera from a Nikon Eclipse E50i optical microscope. The fiber core appeared circular, well centered and featured a diameter of 8 µm, whilst the overall average diameter of the optical fiber was 120 µm. No particular defect or air gap could be observed at the core-cladding interface. The fiber was then considered of good quality and suitable to proceed to further testing and characterization.

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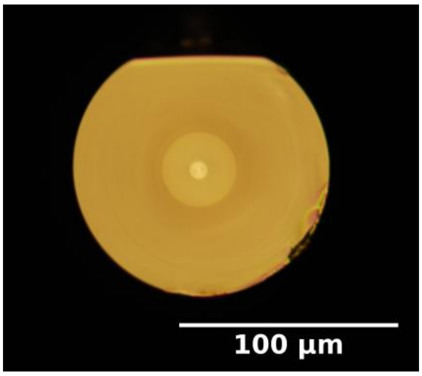

Figure 1 - Optical micrograph of the Tm-Ho optical fiber.

The fiber was characterized in terms of attenuation loss at the wavelength of 980 and 1310 nm by butt coupling a fiber pigtailed single mode laser diode using the cut-back method. The output power of the fiber was collected with a power meter and an attenuation loss of ~2dB/m at 980 and of 1.8 dB/m at 1300nm were measured.

3.4 Fluorescence spectroscopy of the optical fiber by pumping at 793 nm

The Tm-Ho tellurite optical fiber was excited in the core using a a Q-photonics QFLD-795-100S single mode fiber pigtailed laser diode emitting at 793 nm. The laser diode fiber (with a core radius of around 6 µm) was butt coupled to a 10 cm long piece of Tm-Ho doped tellurite optical fiber. The fiber was selected to be not too long to allow uniform pumping along the axis and not too short to allow for a sufficient intensity of amplified spontaneous emission. The excited fiber showed an evident green luminescence (Fig. 2), which was ascribed to the up-conversion fluorescence process.

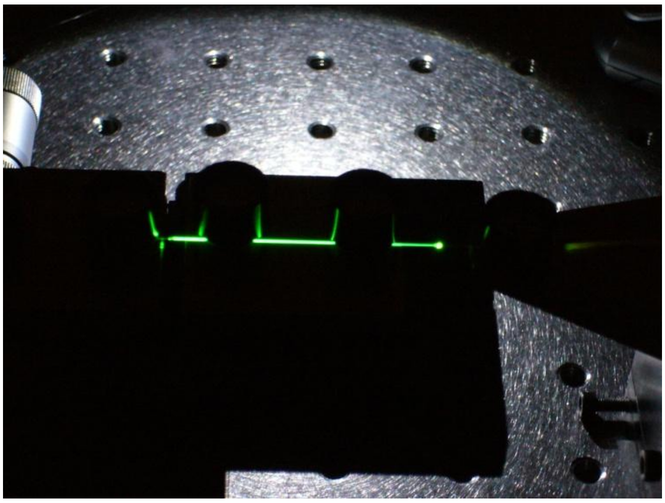

Figure 2 – The green upconversion luminescence of a 10 cm long piece of Tm-Ho fiber under 793 nm pumping.

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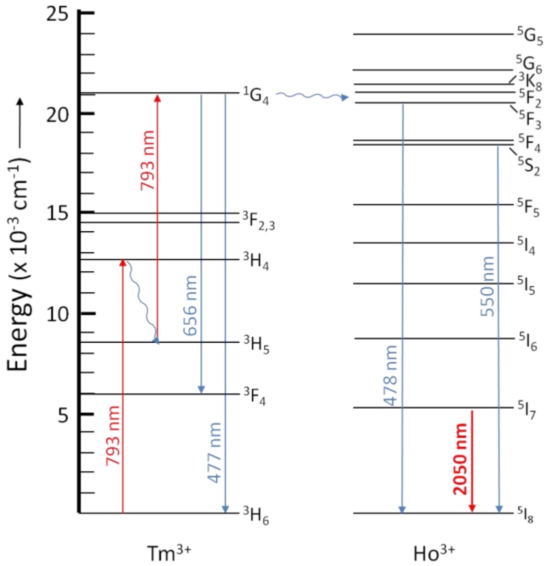

Figure 3 - Energy level diagram of Tm3+ and Ho3+ ions in tellurite glasses. The pump wavelength and the targeted emission wavelength in the near infrared wavelength region are highlighted in red color.

Fluorescence spectra in the visible wavelength region were collected using a multimode optical fiber butt coupled to the Tm-Ho fiber end facet and then focussed into a Hamamatsu photomultiplier tube through a Horiba Jobin Yvon iHR320 monochromator for wavelength selection.

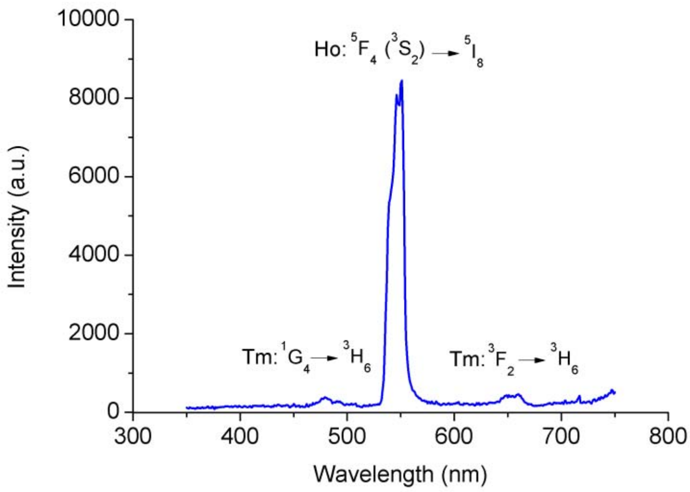

Figure 4 - Visible luminescence spectrum of the Tm-Ho doped tellurite fiber under 976 nm pumping.

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Fig. 4 reports the measured spectrum in the visible region, which features an emission peak centered at around 550 nm corresponding to the Ho^{3+}: $^5F_4(^3S_2) \rightarrow {}^5I_8$ transition. This peak is quite strong and it is reducing the emission efficiency in the infrared region. Further work shall in the future target its minimization.

Luminescence spectra in the near infrared wavelength region were collected using a multimode optical fiber butt coupled to the Tm-Ho fiber end facet and then the ASE signal was focussed into a single channel PbSe photoconductive detector. Wavelength selection was carried out using a Horiba Jobin Yvon iHR320 monochromator. The laser diode used was a Q-photonics QFLD-795-100S and the spectrum reported in Fig. 5 was obtained with a pump power of 100 mW. Absorbed power was estimated to be around 50 mW.

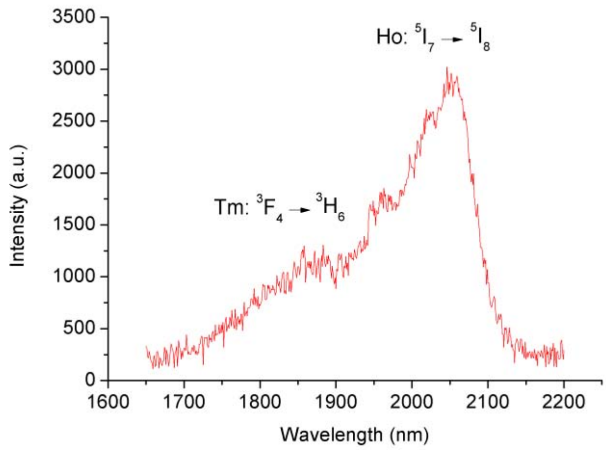

Figure 5 - Luminescence spectra of Tm-Ho tellurite optical fiber in the near IR wavelength region under pumping at 793 nm with a power of 100 mW (estimated absorbed power 50 mW).

The Tm-Ho doped tellurite optical fiber successfully emitted at the peak wavelength of 2050 nm, corresponding to the Ho^{3+}: $^5I_7 \rightarrow {}^5I_8$ transition. A residual emission corresponding to the Tm^{3+}: $^3F_4 \rightarrow {}^3H_6$ transition was recorded.

3.5 Personnel involved in the research activity

The following people contributed to the success of the project:

i. Daniel Milanese, Assistant Professor (PoliTo), 2.4 men months, 14233 USD cost
ii. Guido Perrone, Assistant Professor (PoliTo), 1.9 men months, 14070 USD cost
iii. Monica Ferraris, Full professor (PoliTo), 0.7 men months, 8060 USD cost

Other collaborators were Joris Lousteau for fibre fabrication and Nadia Boetti for testing the optical fiber.

3.6 Conclusions and future work

The present research project reached his goal because it allowed the research group to fabricate and characterize a Tm-Ho doped tellurite fiber, which demonstrated low attenuation loss and emission both in the visible and in the near infrared wavelength range.

The results of this research activity will be presented at the next Cleo Europe 2011 conference in Munich.

Further research activities are foreseen, in particular focussing on:

- The optimization of Tm^{3+} and Ho^{3+} ions concentration
- The minimization of upconversion luminescence, which impairs efficient emission in the near infrared wavelength region
- The development of an optical fiber laser emitting at 2.2 um by pumping at 793 nm

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Torino, November 23 2010

Daniel Milanese

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